The Physico-Chemical Analyses of the Distillate Yields of Solar Stills

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Abstract— In this research, water samples were collected from Kwalkwalawa Dam, Sokoto State, North Western Nigeria. The Dam is the main source of water for drinking, agricultural and other domestic activities by the entire residents of the Kwalkwalawa village. 50 liters of the raw water was distilled between 8.00am and 18.00pm using the double slope solar still water distiller. The physico chemical analyses of both the undistilled water sample and those of the distillates were analyzed. Properties like hardness, pH values, lead contents, manganese contents iron contents, copper contents, zinc contents, cadmium contents, chromium contents, magnesium contents, chloride contents, nitrate contents, sulfate contents and phosphate contents of the samples were determined. Using pH meter (Lab Tech), the pH values of the respective water samples were measured, and the total hardness was measured with the aid of titration technique. The chemical contents were investigated using photometer. The results were tabulated and picturesque and compared with World Health Organization values and other relevant standards. It was observed that, the water samples from Kwalkwalawa Dam were contaminated; the distillate samples were healthy, safe and conform to all relevant standards, whence, the use of solar still distillation technique is recommended for the entire residents of Kwalkwalawa village considering the abundant solar radiation in the area all year round.

Index Terms— Distillate, Solar Still, Chemical Contents, Photometer, World Health Organization

1 INTRODUCTION

Water is essential for the survival of human beings, animals, plants and the entire universe it's self. For human beings, it's not just any form of water they require for sustenance, it must be clean and healthy water that is preferred for cooking, drinking, health care and other domestic uses. Although the cleanest and most healthy water exist in nature: from springs, rainwater and from well drilled boreholes, but yet, no all human beings have direct access to clean water all year round. This is part of the reasons that call for the espousal water purification methods. Water can be purified using some of the following conventional methods: Filtration, distillation, chlorination, evaporation etc.

In this work distillation method was used for solar distillation of water samples collected from Kwalkwalawa dam of Sokoto State using solar stills. This was in order to observe the chemical and physical properties of the distillate compared with WHO standards and whence, to deduce on whether or not, the solar still distillation system will be suitable for use by the common men residing in the rural communities.

The performance of solar still is commonly expressed as the measure of water produced by each unit of the basin area in a day, such as cubic meters or litres per square meter of the basin area per day. The amount of distillate depends on the design of the still, intensity of solar radiation and the atmospheric condition in the surrounding.

Usually, the transparent glass cover, water and basin liner absorbs the incoming radiation with a small fraction of it being reflected back to space by the glass and water surfaces. The absorbed energy in the basin available to produce vapour, and hence distillate, depends on the temperature change of the basin water and on the heat losses from the water basin. Consequently, the heat and mass transfer to the transparent glass cover on the outside coupled with the rate of heat dissipation from the cover on the outside will greatly affect the amount of vapour condensed, and hence the quality of distillate produced.

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2 METHODOLOGIES

Water samples were collected from Kwalkwalawa dam of Sokoto State. In order to achieve a desired output, a double slope solar still was filled with 50L of the water sample. The distillate yield of the solar still was collected from 8.00am to 18.00pm. The essence of this experiment was to test for the chemical composition of the water sample used before and after the distillation and to compare them with WHO standards.

Using photometer (LF 2004, windows), the following cations and anions were measured: Lead (Pb), Iron (Fe), Manganese (Mn), Phosphate (PO4), Nitrate (NO3), Sulphate (SO4), Chloride (Cl), Cadmium(Cd), Chromium (Cr) and Copper (Cu).

Using Digital pH meter (Lab Tech), the pH values of the respective water samples were measured, and the total hardness was measured with the aid of titration technique.

The physical properties (pH and hardness) as well as the chemical composition were tabulated and compared using WHO standard values, and the respective readings were picturesque in bar charts for analyses.

3. RESULTS AND DISCUSSIONS

Table1 below presents the chemical composition and pH/hardness values obtained before and after the solar distillation of water samples from Kwalkwalawa Dam, using solar still distillation method.

TABLE 1 PHYSICO CHEMICAL PROPERTIES OF WATER

Physico-Chemical Properties	Concentration of Un-distilled Water (mg/l)	Concentration of Distilled Water (mg/l)	WHO Guidelines Values (mg/l)
Lead (Pb^{2+}) Content	0.04	0.02	0.050
Iron (Fe^{3+}) Content	0.80	0.20	0.300
Manganese (Mn^{2+}) Content	0.70	0.10	0.300
Phosphate (PO_4) Content	0.30	0.20	-
Nitrate(NO_3^-) Content	2.70	0.50	4.500
Sulphate (SO_4^{2-}) Content	58.00	3.90	4.000
Chloride (Cl^-) Content	2.40	0.90	2.500
Cadmium (Cd) Content	0.04	0.02	0.005
Chromium (Cr) Content	0.14	0.04	0.050
Copper (Cu^{2+}) Content	0.40	0.10	1.000
pH	5.50	6.50	8.500
Total hardness	936.90	35.80	500.000

The various readings of the chemical compositions, hardness and pH for the Kwalkwalawa Dam in Sokoto as well as the WHO Values are presented in the bar charts below:

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4.1 LEAD

From the figure 1 below, it can be seen that, the compositions of lead are 0.04, 0.02 and 0.05 for undistilled water, distilled water and WHO standards respectively. Therefore, both the water samples conform with WHO standards. Signs of chronic lead toxicity, including tiredness, sleeplessness, irritability, headaches, joint pain and gastrointestinal symptoms, may appear in adults at blood lead levels (WHO, 2012).

Lead is the commonest of the heavy elements, constituting up to 13 mg/kg of Earth's crust. Numerous stable isotopes of lead exist in nature, these consist of, in order of abundance, 208Pb, 206Pb, 207Pb and 204Pb. Lead is a soft metal. With melting point of about 345^{0}C.

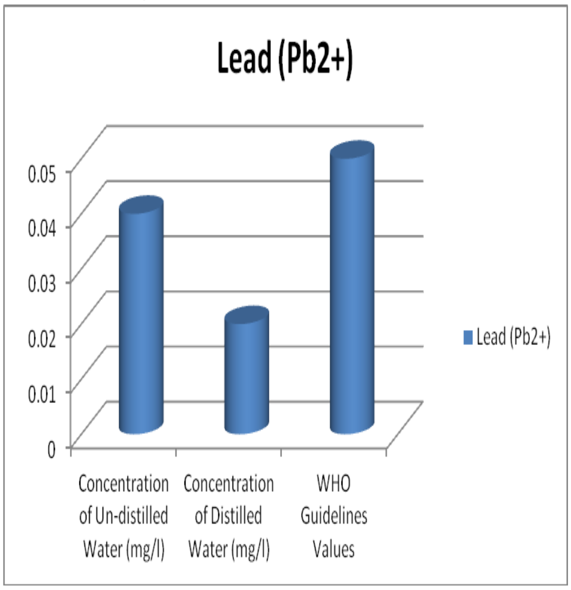

Figure 1 Lead Concentrations

Lead is commonly found in a location which has incessant momentous use in petrol, paint and water pipes, as well as its usual occurrence in soils as a result of local geological conditions. Beyond the 1970s, these uses of lead have been banned across Europe and the human health risks have been studied comprehensively and are generally well understood (Drinking water Inspectorate, 2012).

The health hazards correspond to the way lead can accumulate in the human body. Those at particular risk are newborn and kids for the reason that lead can have an adverse impact on mental growth. Lead may also be a cause of behavioral problems. Globally, it is recommended that human contact with lead is kept to a barest minimum and lead is therefore controlled in air, soil, food and water.

4.2 IRON

Figure 2 shows a bar chart which presents the iron contents in the two water samples as well as the WHO value. The respective values are 0.8mg/L, 0.2mg/L and 0.3mg/L correspondingly for the non-distilled water, distilled water and WHO value. The non distilled water has very high iron content far beyond the WHO standards, while the solar still distilled water has iron content within the acceptable standards and hence is conforming to the WHO.

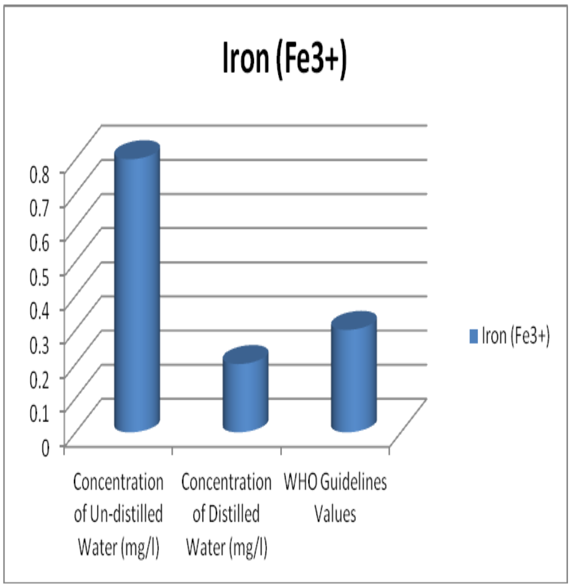

Figure 2 Iron Concentrations

Iron is the second most plentiful metal in the earth's crust, it accounts for about 5%. Elemental iron is infrequently found in nature, as the iron ions $Fe2^{+}$ and $Fe3^{+}$ readily mix up with oxygen- and sulfur-containing compounds to form oxides, hydroxides, carbonates, and sulfides. Iron is most frequently found in nature in the form of its oxides (WHO, 1996).

Iron is a not dangerous, nevertheless occasionally exasperating element present in communal and classified water supplies. High concentrations of dissolved iron can cause poor tasting, unpleasant water that stains both plumbing equipment and clothes. When iron-rich waters blend with tea, coffee, or alcoholic beverages, they assume a black, inky form with a repulsive taste. Vegetables cooked in iron-rich waters also become gloomy and flavorless. Concentrations of iron as low as 0.3 milligrams per liter (mg/L) will deposit reddish-brown dirty on fixtures, utensils, and clothes, all of which can be hard to get rid of (Alex and Mahler, 2006)

4.3 MANGANESE

Manganese can be present in 11 oxidative states; the most environmentally and biologically essential manganese compounds are those that contain Mn^{2+}, Mn^{4+} or Mn^{7+} (USEPA, 1994). Manganese exists in nature in plentiful surface water and groundwater sources and in soils that may wear away into these waters. On the other hand, human actions are also accountable for much of the manganese contamination in water in some vicinity (WHO, 2011).

The US Environmental Protection Agency has a derived standard of 0.05 mg/L, which is projected to let the public be acquainted with the fact that manganese can influence water quality at this level (CT DOH, 2012). From the result above tabulated and figure 3 below, the respective values of manganese in the non-distilled water sample, distilled water sample and the WHO values are: 0.7mg/L, 0.1mg/L and 0.3mg/L. It can be seen that, the residents of Kwalkwalawa village, who drink the undistilled water take excess of manganese.

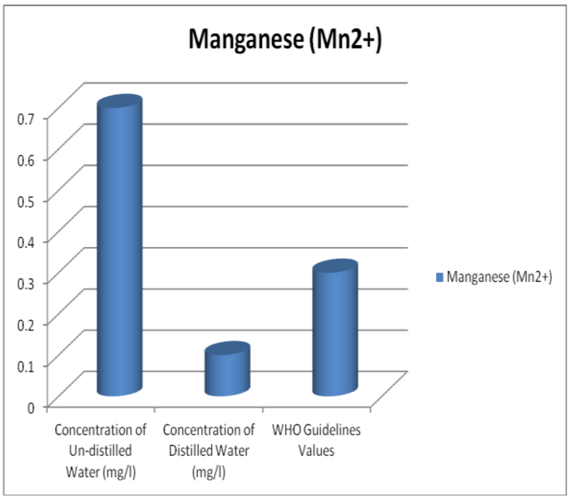

Figure 3 Manganese Concentrations

Furthermore, According to (CT DPH, 2012), exposure to high concentrations of manganese over the course of years has been connected with toxicity to the nervous system, bringing into being, a disease that resembles Parkinsonism. This kind of effect may be more probable to occur in the aged people. The new manganese AL is put low enough to make sure that the eventual nervous system effect will not occur, even in those who may be more vulnerable. Manganese is implausible to produce other types of toxicity such as cancer or reproductive problem.

4.4 PHOSPHATE

Similarly, from the table above, the amount of phosphate varied from 0.3mg/L to 0.2mg/L for non-distilled and distilled water samples respectively. The natural concentrations of phosphate generally range from 0.005 to 0.05 mg/L (James E. K, 1997). Phosphorus occurs in nature simply in the form of chemical compounds, either as inorganic orthophosphate (HPO42-, H2PO4-) or in organic compounds. Total phosphorus can be subdivided into particulate phosphorus and soluble phosphorus (Markku, 2002).

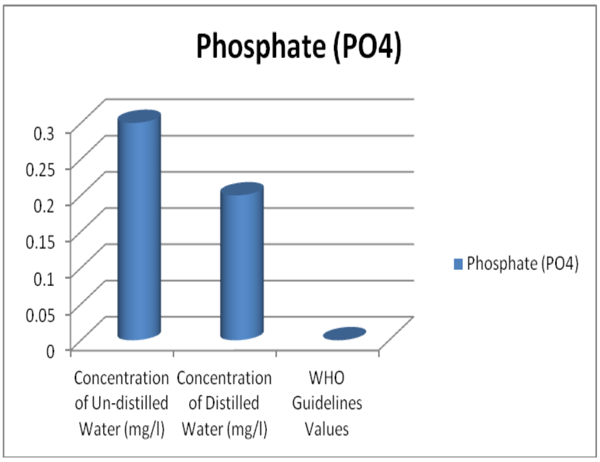

Figure 4 Phosphate Concentrations

4.5 NITRATE

Considering same table above and from the figure 5 below, the respective values for nitrate in un-distilled water sample, distilled water sample and the WHO values are 2.7mg/L, 0.5mg/L and 4.5mg/L.

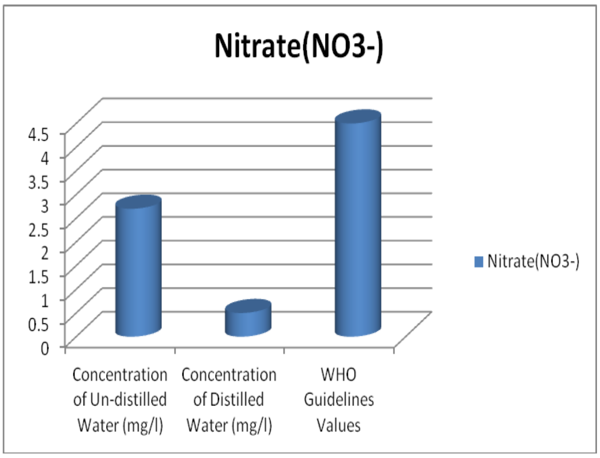

Figure 5 Nitrate Concentrations

In 1962, the U. S. Public Health Service recommended an acceptable level equivalent to 10 parts per million (ppm) or 10 milligrams of nitrate-nitrogen in 1 liter of drinking water (mg/L). In view of the fact that this standard takes available health effects information into account, infants are unlikely to cause methemoglobinemia caused by drinking water that contain nitrite at or below this level (New Jersey, 2012). On Nitrate contained by the human body Peter (2012), related that, nitrate is regarded as less toxic, but nitrite and NOCs are biologically vigorous in mammalian systems. As reduction (Nitrosation) of nitrate produces nitrite and eventually NOCs, it is imperative to reflect on the various exogenous sources of nitrate in contact with the human body. Nutritional nitrate, mainly in vegetables and processed meats, form a major source of ingested nitrate. Nitrate levels in vegetables differ depending on the kind of vegetable and the manner in which it is raised and stored. Concentrations in fresh vegetables are quite small, usually in the range of 1-2 mg/kg and infrequently over 10/mg/kg

4.6 SULPHATE

Sulphates occur physically in numerous minerals, together with barite ($BaSO_4$), epsomite $MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$). These dissolved minerals contribute to the mineral content of countless drinking-waters (WHO 2004).

From the table above and figure 6 below, the sulfate content in the un-distilled water, distilled water and the WHO values are: 58mg/L, 3.9mg/L and 4.0mg/L respectively. It is observed that, the sulphate content in the distilled water using solar still distillation method is within the range of the WHO values. The sulphur content of the un-distilled water is so high and whence, the residents of Kwalkwalawa will likely be affected by this water source they rely on.

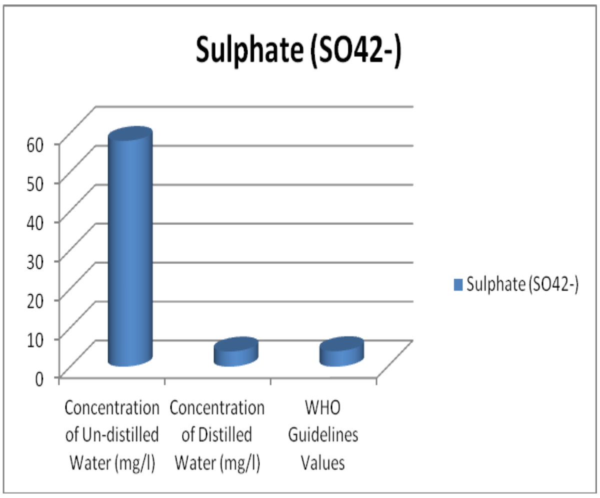

Figure 6 Sulphate Concentrations

4.7 CHLORIDE

Chloride has the values of 2.4mg/L, 0.9mg/L and 2.5 mg/L for the non-distilled, distilled and WHO water values respectively. It is clear that both the non-distilled water sample and the distillate have their chloride values below WHO standards. Chlorides are broadly disseminated in nature as salts of sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$) (WHO, 2003).

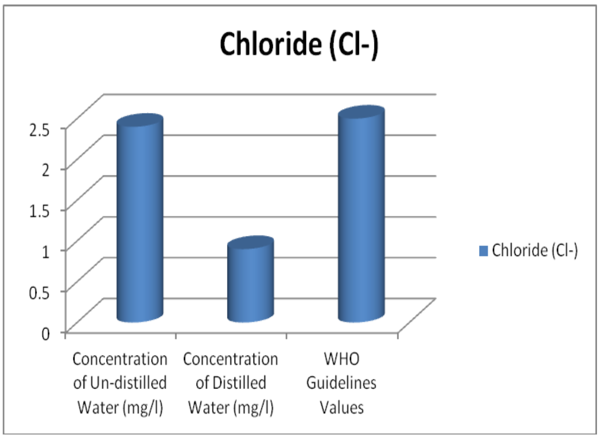

Figure 7 Chloride Concentrations

Concentrated values of sodium and chloride to some extent increase the water's ionic conductance, and thus somewhat increase the prospect for corrosive water damage to plumbing fittings. To lessen this damage, a whole-house water treatment system would be needed (New Hampshire, 2010). This calls for the need to use solar still for water distillation in Kwalkwalawa.

4.8 CADMIUM

Cadmium is a metal with an oxidation state of +2. It is chemically comparable with zinc and occurs physically with zinc and lead in sulphide ores (WHO, 2011). Cadmium metal is mainly used as an anticorrosive so its been electroplated onto steel. Cadmium sulfide and selenide are normally used as pigments in plastics. Cadmium compounds are also used in electric batteries, electronic components and nuclear reactors.

From the experimental result, cadmium has the values of 0.04mg/L, 0.02mg/L and 0.05mg/L in the un-distilled water sample, the distillate and the WHO standards respectively.

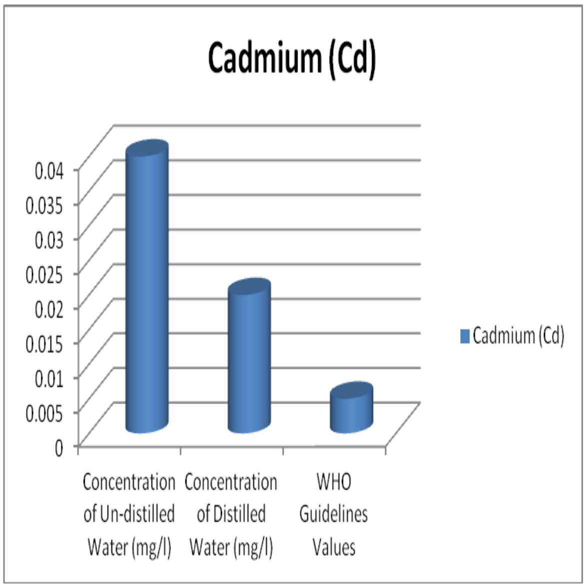

Figure 8 Cadmium Concentrations

The United State Environmental Protection Agency (EPA) has recognized a Maximum Contaminant Level (MCL) of 0.005 milligrams per litre (mg/L) for cadmium in drinking water. The Agency has discovered cadmium to possibly cause a diversity of effects from sharp exposures, including: nausea, vomiting, diarrhoea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure. Drinking water levels which are considered "safe" for short-term exposures are: 0.04 mg/L for a 10-kg (22 lb.) child consuming 1 litre of water per day for one- to ten-day exposures, and 0.005 mg/L for a longer term (up to 7 years) exposure (Water Quality Association, 2004).

4.9 CHROMIUM

From our findings as tabulated above and picturesque below in figure 9, the respective values for Chromium in un-distilled water sample, distillate and the WHO standards are: 0.14mg/L, 0.04mg/L and 0.05mg/L. Chromium is widely distributed in the earth's crust. It can exist in oxidation states of +2 to +6. Soils and rocks may contain small amounts of chromium, almost always in the trivalent state (WHO, 2004).

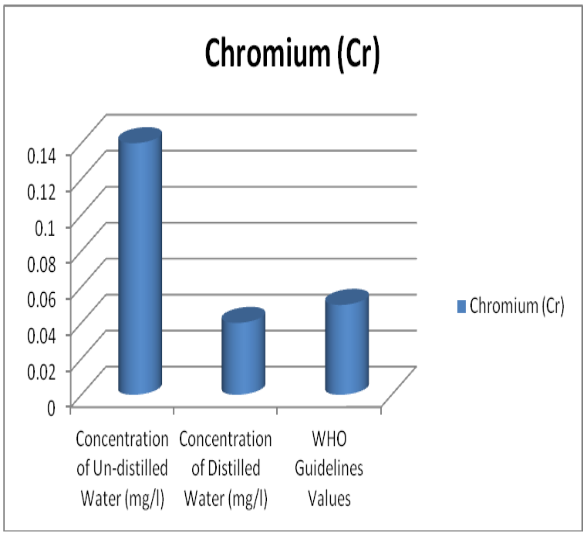

Figure 9 Chromium Concentrations

According to the California Public Health Goal (1999), the Office of Environmental Health Hazard Assessment (OEHHA) has developed a Public Health Goal (PHG) of 2.5·10-3 mg/L (2.5 µg/L, 2.5 ppb) for total chromium. The California Maximum Contaminant Level (MCL) is currently 0.05 mg/L (50 ppb) for total chromium in drinking water. There are two types of chromium, chromium VI and chromium III, that may be significant as drinking water contaminants. OEHHA believes that the health protective goals of the California Safe Drinking Water Act of 1996 are best served by assuming that chromium VI is carcinogenic when ingested.

4.10 COPPER

Copper is a metal that exists in nature as a mineral in rocks and soil. It is usually found at low concentrations in natural water bodies. It is also a fundamental trace element that is necessary to maintain good health. Copper pipes are used expansively in plumbing systems all through Western Australia and in many countries of the world (Department of Health, Western Australia 2010).

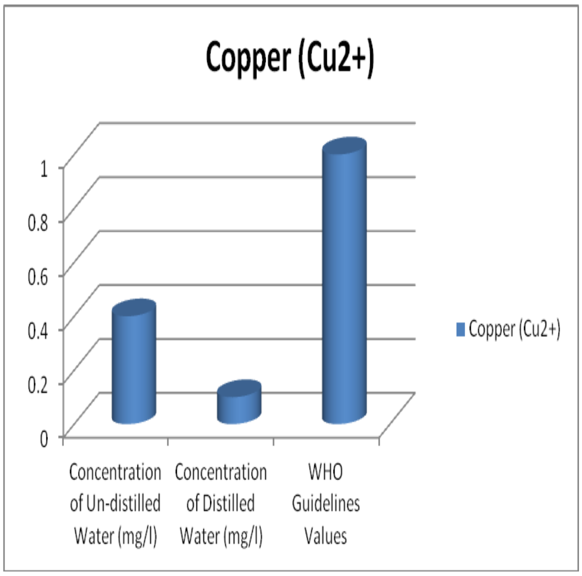

Figure 10 Copper Concentrations

From the experimental result afore presented, the values of copper in the non-distilled water sample from Kwalkwalawa dam, the distillate formed using solar still and the WHO standards are: 0.4mg/L, 0.1mg/L and 1.0mg/L correspondingly. Here, the amount of copper present in both the distilled and non-distilled water conforms to the WHO standards.

4.11 THE pH VALUES

The pH values of the water samples and the WHO value from our findings are as follows: 5.5, 6.5 and 8.5 respectively. The U.S. Environmental Protection Agency (EPA) does not regulate the pH level in drinking water. It is classified as a secondary drinking water contaminant whose impact is considered aesthetic. However, the EPA recommends that public water systems maintain pH levels of between 6.5 and 8.5, a good guide for individual well owners (EPA, 2007).

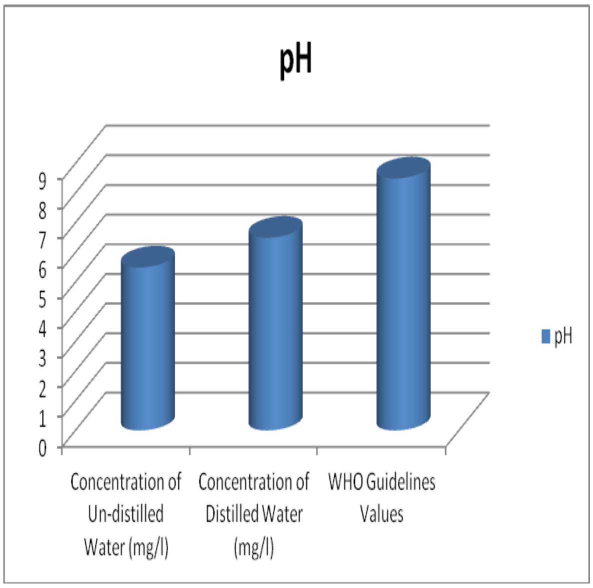

Figure 11 pH Values

The pH of a solution is the negative common logarithm of the hydrogen ion activity: pH = -log (H+). In dilute solutions, the hydrogen ion activity is roughly equal to the hydrogen ion concentration. The pH of water is a measure of the acid–base equilibrium and, in most natural waters, is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. An improved carbon dioxide concentration will therefore lower pH, whereas a reduced concentration will cause it to rise (WHO, 2003).

4.12 TOTAL HARDNESS

Hardness in drinking water is defined as those minerals, which dissolve in water, that have a divalent (positive two) electrical charge. Minerals are composed of either atoms or molecules. An atom or molecule that has dissolved in water is called an "ion". The primary components of hardness are calcium (Ca^{++}) and magnesium (Mg^{++}) ions. Dissolved iron (Fe^{++}) and manganese (Mn^{++}) also satisfy the definition of hardness but typically make up only a very small fraction of total hardness. Positively charged ions are called cations (EAI, 2012).

According to the WHO (2011), water hardness is the conventional measure of the ability of water to react with soap, hard water require significantly more soap to turn out a lather. Hard water habitually produces a perceptible deposit of precipitate (e.g. insoluble metals, soaps or salts) in containers, including "bathtub ring". It is not caused by a single substance but by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations, although other cations (e.g. aluminium, barium, iron, manganese, strontium and zinc) also contribute. Hardness is generally expressed as milligrams of calcium carbonate equivalent per litre. Water containing calcium carbonate at concentrations below 60 mg/L is generally considered as soft; 60–120 mg/L, moderately hard; 120–180 mg/L, hard; and more than 180 mg/L, very hard. Although hardness is caused by cations, it may also be discussed in terms of carbonate (temporary) and non-carbonate (permanent) hardness.

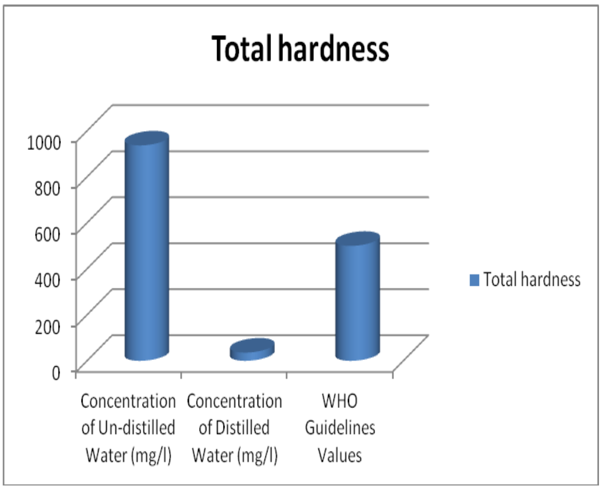

Figure 12 Hardness in Water Samples

From the Result of our experiment, the un-distilled water from Kwalkwalawa has the hardness of 936.9mg/L, the distillate has recorded the hardness of 35.8mg/L and the WHO value is 500mg/L.

5.0 CONCLUSION

The un-distilled water from Kwalkwalawa Dam, which is the main source of drinking water for the neighborhood, is contaminated and hazardous to human life. The physico chemical analyses of distillate yields by the solar still distillation method and those of the raw un-distilled water from Kwalkwalawa, Sokoto State have vindicated the paramount significance of the use of solar still in the area. The amount of solar radiation in the area is more than enough to be utilized by the respective households within the community in purifying their drinking water for health, safety and confort.

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